

CERN-TH/2000-006
hep-ph/0001044

The MSSM at present and future colliders ‡

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Abstract

A brief overview over the phenomenology of the MSSM at present and future colliders is given. The complementarity of indirect tests of the model via precision observables and of the information from the direct production of SUSY particles is emphasized. If the lightest Higgs boson of the MSSM will be detected, its mass will also play an important role as a precision observable.

‡ Presented at the “International Europhysics Conference on High Energy Physics”, Tampere, July 1999.

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A brief overview over the phenomenology of the MSSM at present and future colliders is given. The complementarity of indirect tests of the model via precision observables and of the information from the direct production of SUSY particles is emphasized. If the lightest Higgs boson of the MSSM will be detected, its mass will also play an important role as a precision observable.

1. Introduction

Supersymmetric (SUSY) theories possess very appealing theoretical properties (for a review, see e.g. Ref. [1]) and can certainly be called the currently best motivated extensions of the Standard Model (SM). Their minimal realization, the Minimal Supersymmetric Standard Model (MSSM), postulates superpartners to the SM fields and requires an enlarged Higgs sector with two Higgs doublets giving rise to five physical Higgs-boson states.

While the MSSM is minimal in the sense of its particle content, in its unconstrained form (i.e. without specific assumptions about the SUSY-breaking mechanism) it introduces more than 100 free parameters (masses, mixing angles, etc.) in addition to the SM parameters. If low-energy Supersymmetry turns out to be realized in nature and superpartners will be found at the present or the next generation of colliders, the determination of the MSSM parameters will be a very demanding task, both from the experimental and the theoretical side. A precise determination of the model parameters will not only be important in order to investigate whether the MSSM is consistent with the data, but also to infer possible patterns of the underlying SUSY-breaking mechanism from the spectrum of the SUSY particles.

In this context it will be important to take advantage of all possible sources of information, i.e. both from the direct production of SUSY particles and from indirect constraints on the model via precision observables.

2. Direct production of SUSY particles

A detailed investigation of the production and decay processes of SUSY particles is indispensable for the

SUSY searches at present and future colliders, as the main background for SUSY signals will often be SUSY itself. For production processes at hadron colliders QCD corrections are very important. In general they give rise to a considerable enhancement of the production cross sections (for recent reviews, see Ref. [2]). Complementary to the hadron colliders Tevatron and LHC, where in particular the latter has a large discovery potential for a wide range of SUSY processes, an e^+e^- linear collider provides high-precision information for all kinematically accessible SUSY particles (see Ref. [3] for an overview). In the context of constraining the parameters of the model it can be very useful to take advantage of polarization of the e^- and also the e^+ beam or to study spin correlations in the production and subsequent decay of SUSY particles (see Ref. [4] and references therein).

As an example for the production of scalar top quarks at a linear collider with $\sqrt{s} = 500$ GeV [5,6], Fig. 1 shows the determination of the mass of the lightest scalar top quark and the mixing angle in the \tilde{t} sector from the cross sections with polarization of the e^- beam of ± 0.9 . As shown in the figure, for an integrated luminosity of $\mathcal{L} = 500 \text{ fb}^{-1}$ a very precise measurement could be possible.

3. The lightest Higgs boson in the MSSM

In contrast to the SM, the mass of the lightest \mathcal{CP} -even Higgs boson in the MSSM, m_h , is not a free parameter, but is calculable from the other parameters of the model. It is bounded to be smaller than the Z-boson mass at the tree level. This bound, however, is strongly affected by large radiative corrections. The dominant corrections arise from the t - \tilde{t} sector of the MSSM. At two-loop order an upper bound on m_h of about $m_h \lesssim 135$ GeV is obtained [7].

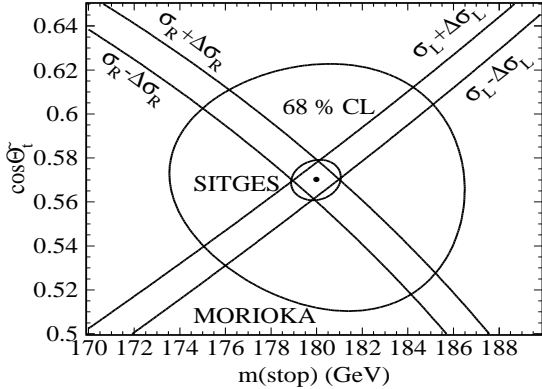


Figure 1. Parameter determination in the scalar top sector of the MSSM at a linear collider with $\sqrt{s} = 500$ GeV and a polarization of $+0.9$ (cross section σ_R) and -0.9 (cross section σ_L) of the e^- beam. For the simulation an integrated luminosity of $\mathcal{L} = 500 \text{ fb}^{-1}$ (small contour) and of $\mathcal{L} = 10 \text{ fb}^{-1}$ (large contour) has been assumed (taken from Ref. [6]).

This upper bound on m_h is a definite and robust prediction of the MSSM, which can be tested at the present and the next generation of colliders. By comparing the present experimental limit on m_h from the search at LEP2 with the theoretical result for the upper bound on m_h in the MSSM as a function of $\tan\beta$, it is possible to derive constraints on $\tan\beta$. For recent analyses in this context, see Ref. [8,9].

If the lightest \mathcal{CP} -even Higgs boson of the MSSM will be found, its mass will be determined with high precision. The prospective accuracy at the LHC is $\Delta m_h = 0.2 \text{ GeV}$ [10], while at a future linear collider an accuracy of even $\Delta m_h = 0.05 \text{ GeV}$ [11] could be achievable.

4. Precision tests of the MSSM

Complementary to the direct production processes of SUSY particles, constraints on the model can also be obtained from the virtual contributions of SUSY particles to SM processes. In global fits to the electroweak data taken at LEP, SLC and the Tevatron the fit quality in the MSSM is similar to the SM case [12]. In the low energy regime rare B decays have turned out to be sensitive probes for physics beyond the SM [13].

Of particular importance for deriving indirect constraints on the MSSM are the precision observables M_W , $\sin^2\theta_{\text{eff}}$, and in the future

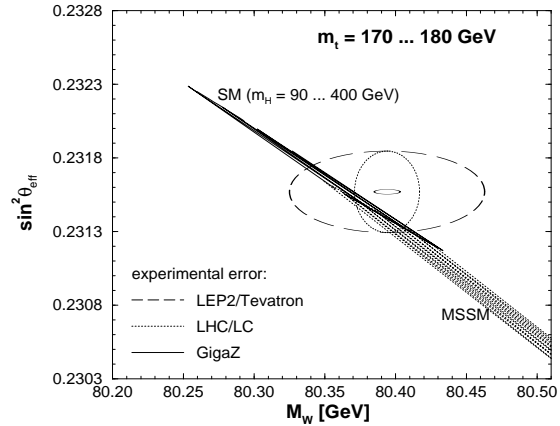


Figure 2. Theoretical prediction of the SM and the MSSM in the $\sin^2\theta_{\text{eff}}-M_W$ -plane compared with expected experimental accuracies at LEP2/Tevatron, the LHC and GigaZ.

possibly also m_h . In Fig. 2 the SM and the MSSM predictions for M_W and $\sin^2\theta_{\text{eff}}$, based on the complete one-loop results and the leading higher-order QCD and electroweak corrections (see Ref. [14] and references therein), are compared with the experimental accuracy obtainable at LEP2, SLC and the Tevatron as well as with prospective future accuracies at the LHC and at a high-luminosity linear collider in a dedicated low-energy run (GigaZ) [15]. The experimental accuracies assumed in Fig. 2 for LEP2/Tevatron, LHC and GigaZ are $\Delta M_W = 30 \text{ MeV}$, 15 MeV , 6 MeV and $\Delta \sin^2\theta_{\text{eff}} = 1.8 \times 10^{-4}$, 1.8×10^{-4} , 1×10^{-5} , respectively. The allowed region of the SM prediction corresponds to varying m_h in the interval $90 \text{ GeV} \leq m_h \leq 400 \text{ GeV}$ and m_t within its present experimental uncertainty, while in the region of the MSSM prediction besides the uncertainty of m_t also the SUSY parameters are varied. As can be seen in the figure, the precision observables M_W and $\sin^2\theta_{\text{eff}}$ provide a very sensitive test of the theory, in particular in the case of the GigaZ accuracy. It should be noted that with a future detection of the Higgs boson, a prospective reduction on the experimental error of m_t to $\Delta m_t = 2 \text{ GeV}$ at the LHC [10] and $\Delta m_t = 0.2 \text{ GeV}$ at a linear collider [11], and with the possible detection of SUSY particles the allowed range of the theory prediction in Fig. 2 will be drastically reduced.

The prediction for m_h within the MSSM is particularly sensitive to the parameters in the $t-t$ sector, while in the region of large M_A and large $\tan\beta$ (giving rise to Higgs masses beyond the reach of LEP2) the dependence on the latter

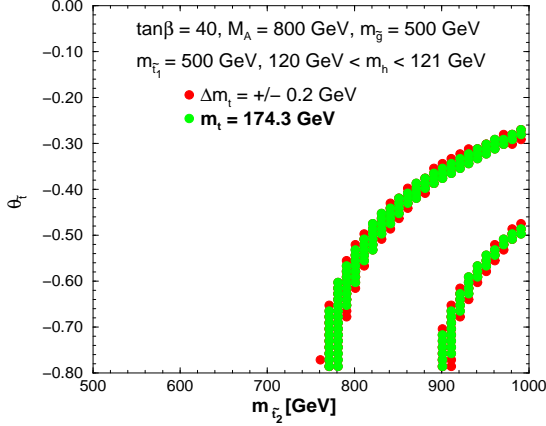


Figure 3. Indirect constraints on the parameters of the scalar top sector of the MSSM from a precision measurement of m_h .

two parameters is relatively mild. A precise measurement of m_h can thus be used to constrain the parameters in the t - \bar{t} sector of the MSSM.

In Fig. 3 it is assumed that the mass of the lightest scalar top quark, $m_{\tilde{t}_1}$, is known with high precision, while the mass of the heavier scalar top quark, $m_{\tilde{t}_2}$, and the mixing angle $\theta_{\tilde{t}}$ are treated as free parameters. The Higgs boson mass is assumed to be known with an experimental precision of ± 0.5 GeV (and a hypothetical value for the central value of m_h is considered), and $\Delta m_t = 0.2$ GeV is used. The figure shows that the values of $m_{\tilde{t}_2}$, $\theta_{\tilde{t}}$ which are compatible with a Higgs-mass prediction of $m_h = 120.5 \pm 0.5$ GeV are given by two narrow bands in the $m_{\tilde{t}_2}$ - $\theta_{\tilde{t}}$ plane (the bands corresponding to smaller and larger values of $m_{\tilde{t}_2}$ are related to smaller and larger values of the off-diagonal entry in the scalar top mixing matrix, respectively). The uncertainty of $\Delta m_t = 0.2$ GeV assumed in Fig. 3 is seen to have only a marginal effect. Combining the constraints on the parameters in the scalar top sector with the constraints from the precision observables M_W and $\sin^2 \theta_{\text{eff}}$ and with the information from the direct production of the scalar top quarks (see Fig. 1) will clearly lead to a very sensitive test of the MSSM. In Fig. 3 the theoretical uncertainty in the Higgs-mass prediction from unknown higher-order contributions and the parametric uncertainty related to all parameters besides $m_{\tilde{t}_2}$, $\theta_{\tilde{t}}$, and m_t has been neglected. In a more realistic analysis these uncertainties, in particular the dependence on the other SUSY parameters according to the available experimental information on these parameters, will have to be taken into account.

The author thanks S. Heinemeyer, W. Hollik and P.M. Zerwas for collaboration and W. de Boer, J. Erler, M. Krämer, S. Kraml, G. Moortgat-Pick, C. Schappacher, A. Sopczak and U. Schwickerath for useful communications.

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